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Topic: SYNCHRONOUS MACHINE

SYNCHRONOUS MACHINE

Synchronous Machine constitutes of both synchronous motors as well as synchronous generators. An AC system has some advantages over DC system. Therefore, the AC system is exclusively used for generation, transmission and distribution of electric power. The machine which converts mechanical power into AC electrical power is called as **Synchronous Generator** or Alternator. However, if the same machine can be operated as a motor is known as **Synchronous Motor.**

A synchronous machine is an AC machine whose satisfactory operation depends upon the maintenance of the following relationship.

$$Ns = \frac{120\ X\ f}{P}\ \text{RPM} \qquad \text{....... (1)}$$

$$or \qquad f = \frac{P\ X\ Ns}{120}\ \text{Hz.} \qquad \text{.......(2)}$$

Where,

- N_s is the synchronous speed in revolution per minute (r.p.m)
- f is the supply frequency
- P is the number of poles of the machine.

When connected to an electric power system, a synchronous machine always maintains the above relationship shown in the equation (1).

If the synchronous machine working as a motor fails to maintain the average speed (N_s) the machine will not develop sufficient torque to maintain its rotation and will stop. Then the motor is said to be **pulled out of Step.**

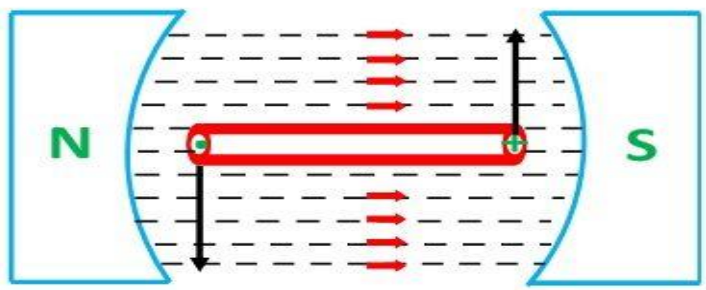
In case, when the synchronous machine is operating as a generator, it has to run at a fixed speed called Synchronous speed to generate the power at a particular frequency. As all the appliances or machines are designed to operate at this frequency. In some countries, the value of the frequency is 50 hertz.

Basic Principles of Synchronous Machine

A synchronous machine is just an electromechanical transducer which converts mechanical energy into electrical energy or vice versa. The fundamental phenomenon or law which makes these conversions possible are known as the **Law of Electromagnetic Induction** and **Law of interaction.**

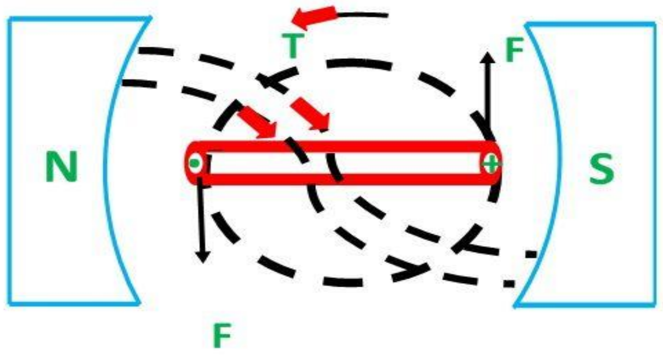
Law of Electro-Magnetic Induction

This law is also called as Faraday's First Law of Electromagnetic Induction. This law relates to the production of emf, i.e.; emf is induced in a conductor whenever it cuts across the magnetic field as shown below.



Law of Interaction

This law relates to the production of force or torque, i.e., whenever a current carrying conductor is placed in the magnetic field, by the interaction of the magnetic field produced by the current carrying conductor and the main field, force is exerted on the conductor producing torque. The figure is shown below.



Construction of a Synchronous Machine

Construction of a Synchronous Machine, i.e. alternator or motor consists of two main parts, namely the stator and the rotor. The stator is the stationary part of the machine. It carries the armature winding in which the voltage is generated. The output of the machine is taken from the stator. The rotor is the rotating part of the machine. The rotor produces the main field flux.

The important parts of the Synchronous Machine are given below.

Stator Construction

The stationary part of the machine is called Stator. It includes various parts like stator frame, stator core, stator windings and cooling arrangement. They are explained below in detail.

Stator Frame

It is the outer body of the machine made of cast iron, and it protects the inner parts of the machine.

Stator Core

The stator core is made of silicon steel material. It is made from a number of stamps which are insulated from each other. Its function is to provide an easy path for the magnetic lines of force and accommodate the stator winding.

Stator Winding

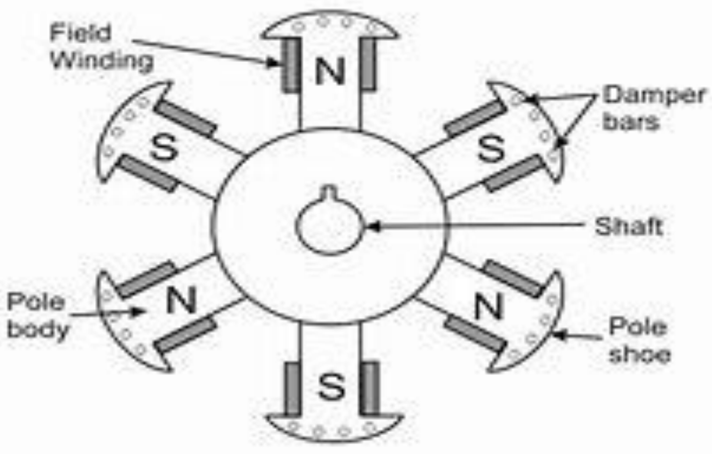
Slots are cut on the inner periphery of the stator core in which 3 phase or 1 phase winding is placed. Enameled copper is used as winding material. The winding is star connected. The winding of each phase is distributed over several slots. When the current flows in a distributed winding it produces an essentially sinusoidal space distribution of EMF.

Rotor Construction

The rotating part of the machine is called Rotor. There are two types of rotor construction, namely the salient pole type and the cylindrical rotor type.

Salient Pole Rotor

The term salient means projecting. Thus, a salient pole rotor consists of poles projecting out from the surface of the rotor core. The end view of a typical 6 pole salient pole rotor is shown below in the figure.



Six pole salient pole rotor

Since the rotor is subjected to changing magnetic fields, it is made of steel laminations to reduce eddy current losses. Poles of identical dimensions are assembled by stacking laminations to the required length. A salient pole synchronous machine has a non-uniform air gap. The air gap is minimized under the pole centres and it is maximum in between the poles.

They are constructed for the medium and low speeds as they have a large number of poles. A salient pole generator has a large diameter. The salient pole rotor has the following important parts.

Spider

It is made of cast iron to provide an easy path for the magnetic flux. It is keyed to the shaft and at the outer surface, pole core and pole shoe are keyed to it.

Pole Core and Pole Shoe

It is made of laminated sheet steel material. Pole core provides least reluctance path for the magnetic field and pole shoe distributes the field over the whole periphery uniformly to produce a sinusoidal wave.

Field Winding or Exciting Winding

It is wound on the former and then placed around the pole core. DC supply is given to it through slip rings. When direct current flow through the field winding, it produces the required magnetic field.

Damper Winding

At the outermost periphery, holes are provided in which copper bars are inserted and short-circuited at both the sides by rings forming Damper winding.

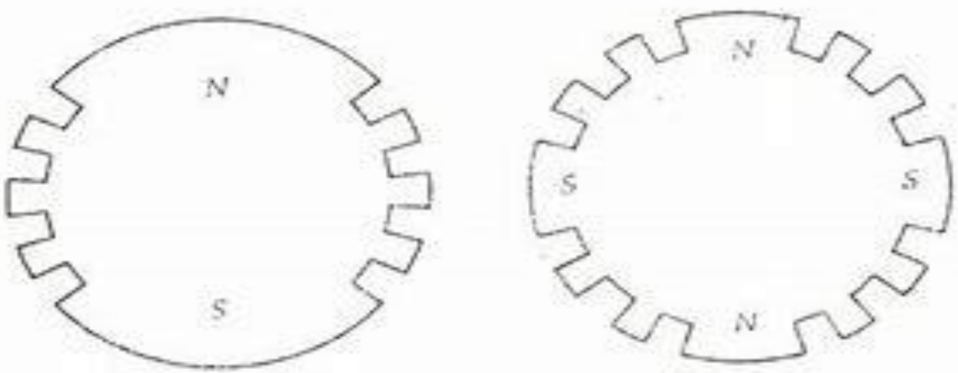
Non- Salient Pole Rotor or Cylindrical Rotor

In this type of rotor, there are no projected poles, but the poles are formed by the current flowing through the rotor exciting winding. Cylindrical rotors are made from solid forgings of high-grade nickel chrome molybdenum steel. It has a comparatively small diameter and long axial length.

They are useful in high-speed machines. The cylindrical rotor type alternator has two or four poles on the rotor. Such a construction provides a greater mechanical strength and permits more accurate dynamic balancing. The smooth rotor of the machine makes less windage losses and the operation is less noisy because of the uniform air gap.

They are driven by steam or gas turbines. Cylindrical synchronous rotor synchronous generators are called turbo alternators and turbo generators.

The figure below shows the end view of the 2 pole and 4 pole cylindrical rotors.



Non salient pole type rotors have the following parts. They are as follows:

Rotor Core

The rotor core is made of silicon steel stampings. It is placed on the shaft. At the outer periphery, slots are cut in which exciting coils are placed.

Rotor Winding or Exciting Winding

It is placed on the rotor slots, and current is passed through the winding in such a way that the poles are formed according to the requirement.

Slip Rings

Slip rings provide DC supply to the rotor windings.

Miscellaneous Parts

The miscellaneous parts are given below.

Brushes

Brushes are made of carbon, and they slip over the slip rings. A DC supply is given to the brushes. Current flows from the brushes to the slip rings and then to the exciting windings.

Bearings

Bearings are provided between the shaft and the outer stationary body to reduce the friction. They are made of high carbon steel.

Shaft

The shaft is made of mild steel. Mechanical power is taken or given to the machine through the shaft.

E.M.F. Equation of Synchronous Machine

Let,

P be the number of poles
ϕ is Flux per pole in Webers
N is the speed in revolution per minute (r.p.m)
f be the frequency in Hertz
Z_{ph} is the number of conductors connected in series per phase
T_{ph} is the number of turns connected in series per phase
K_c is the coil span factor
K_d is the distribution factor

Flux cut by each conductor during one revolution is given as **ϕP** Wb

Time taken to complete one revolution is given by **60/N** sec.

Average EMF induced per conductor will be given by the equation

$$\frac{P\varphi}{60/N} = \frac{P\varphi N}{60} \quad \text{volts}$$

Average EMF induced per phase will be

$$\frac{P\varphi N}{60} \times Z_{ph} = \frac{P\varphi N}{60} \times 2T_{ph} \quad \text{and}$$

$$T_{ph} = \frac{Z_{ph}}{2}$$

$$\text{Average EMF} = 4 \times \varphi \times T_{ph} \times \frac{PN}{120} = 4\varphi f T_{ph}$$

The average EMF equation is derived with the following assumptions given below.

- ✓ Coils have got the full pitch.
- ✓ All the conductors are concentrated in one stator slot.

Root mean square (R.M.S) value of the EMF induced per phase is given by the equation,

E_{ph} = Average value x form factor

$$\therefore \quad E_{ph} = 4\varphi f T_{ph} \text{ x } 1.11 = 4.44\, \varphi\, f\, T_{ph} \text{ volts}$$

If the coil span factor K_c and the distribution factor K_d , are taken into consideration than the Actual EMF induced per phase is given as

$$E_{ph} = 4.44\, K_c K_d \varphi\, f\, T_{ph} \text{ volts} \quad .... (1)$$

Equation (1) shown above is the EMF equation of the Synchronous Generator.

Coil Span Factor

The Coil Span Factor is defined as the ratio of the induced emf in a coil when the winding is short pitched to the induced emf in the same coil when the winding is full pitched.

Distribution Factor

Distribution factor is defined as the ratio of induced EMF in the coil group when the winding is distributed in a number of slots to the induced EMF in the coil group when the winding is concentrated in one slot.

Synchronous Motor

The motor which runs at synchronous speed is known as the synchronous motor. The synchronous speed is the constant speed at which motor generates the electromotive force. The synchronous motor is used for converting the electrical energy into mechanical energy.

Construction of Synchronous Motor

The stator and the rotor are the two main parts of the synchronous motor. The stator becomes stationary, and it carries the armature winding of the motor. The armature winding is the main winding because of which the EMF induces in the motor. The rotator carry the field windings. The main field flux induces in the rotor. The rotor is designed in two ways, i.e., the salient pole rotor and the non-salient pole rotor.

The synchronous motor uses the salient pole rotor. The word salient means the poles of the rotor projected towards the armature windings. The rotor of the synchronous motor is made with the laminations of the steel. The laminations reduce the eddy current loss occurs on the winding of the transformer. The salient pole rotor is mostly used for designing the medium and low-speed motor. For obtaining the high-speed cylindrical rotor is used in the motor.

Synchronous Motor Working

The stator and rotor are the two main parts of the synchronous motor. The stator is the stationary part, and the rotor is the rotating part of the machine. The three-phase AC supply is given to the stator of the motor.

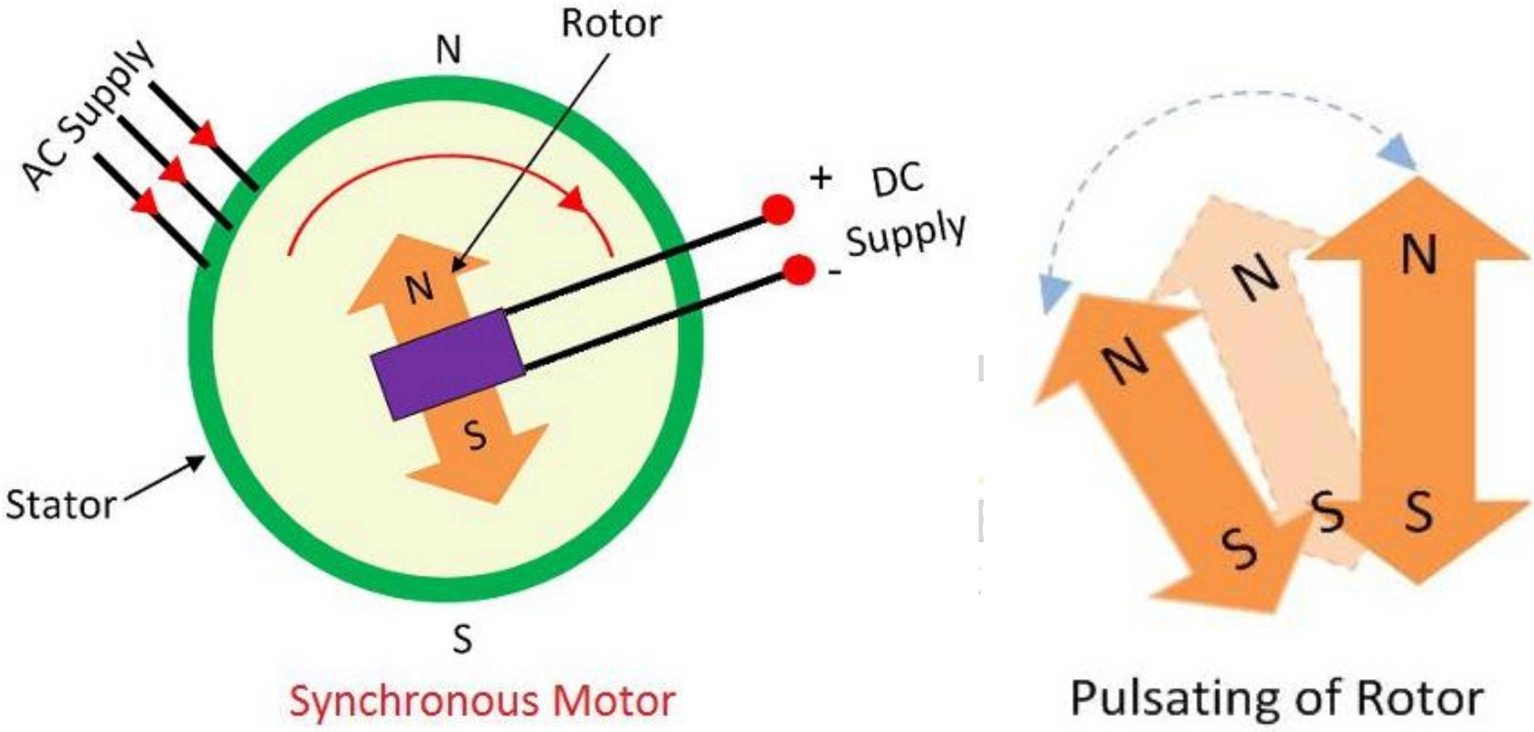
The stator and rotor both are excited separately. The excitation is the process of inducing the magnetic field on the parts of the motor with the help of an electric current.

When the three phase supply is given to the stator, the rotating magnetic field developed between the stator and rotor gap. The field having moving polarities is known as the rotating magnetic field. The rotating magnetic field develops only in the polyphase system. Because of the rotating magnetic field, the north and south poles develop on the stator.

The rotor is excited by the DC supply. The DC supply induces the north and south poles on the rotor. As the DC supply remains constant, the flux induces on the rotor remains same. Thus, the flux has fixed polarity. The North Pole develops on one end of the rotor, and the South Pole develops on another end.

The AC is sinusoidal. The polarity of the wave changes in every half cycle, i.e., the wave remains positive in the first half cycle and becomes negative in the second half cycle. The positive and negative half cycle of the wave develops the north and South Pole on the stator respectively.

When the rotor and stator both have the same pole on the same side, they repel each other. If they have opposite poles, they attract each other. This can easily be understood with the help of the figure shown below.



The rotor attracts towards the pole of the stator for the first half cycle of the supply and repulse for the second half cycle. Thus the rotor becomes pulsated only at one place. This is the reason because of which the synchronous motor is not self-starting.

The prime mover is used for rotating the motor. The prime mover rotates the rotor at their synchronous speed. The synchronous speed is the constant speed of the machine whose value depends on the frequency and the numbers of the pole of the machine.

When the rotor starts rotating at their synchronous speed, the prime mover is disconnected to the motor. And the DC supply is provided to the rotor because of which the north and South Pole develops at their ends

The north and south poles of the rotor and the stator interlock each other. Thus, the rotor starts rotating at the speed of the rotating magnetic field. And the motor runs at the synchronous speed. The speed of the motor can only be changed by changing the frequency of the supply.

Main Features of Synchronous Motor

- The speed of the synchronous motor is independent of the load, i.e., the variation of the load does not affect the speed of the motor.
- The synchronous motor is not self-starting. The prime mover is used for rotating the motor at their synchronous speed.
- The synchronous motor operates both for leading and lagging power factor.

The synchronous motor can also be started with the help of the damper windings.

Difference between Induction Motor and Synchronous Motor

BASIS OF DIFFERENCE	SYNCHRONOUS MOTOR	INDUCTION MOTOR
Type of Excitation	A synchronous motor is a doubly excited machine.	An induction motor is a single excited machine
Supply System	Armature winding is energized from an AC source and its field winding from a DC source.	Stator winding is energized from an AC source.
Speed	Always runs at synchronous speed. The speed is independent of load.	If the load increased the speed of the induction motor decreases. It is always less than the synchronous speed.
Starting	It is not self-starting. It has to be run up to synchronous speed by any means before it can be synchronized to AC supply.	Induction motor has self-starting torque.
Operation	A synchronous motor can be operated with lagging and leading power by changing its excitation.	An induction motor operates only at a lagging power factor. At high loads the power factor becomes very poor.
Efficiency	It is more efficient than an induction motor of the same output and voltage rating.	Its efficiency is lesser than that of the synchronous motor of the same output and the voltage rating.
Cost	A synchronous motor is costlier than an induction motor of the same output and voltage rating	An induction motor is cheaper than the synchronous motor of the same output and voltage rating.

SOLVED PROBLEMS

Q.1. A 3 - phase, 50 Hz, synchronous generator runs at 375 rpm. What is the number of poles of the machine?

Solution:

Frequency, f = 50 Hz

Speed Ns = 375 rpm

Therefore, No. of poles of the machine, P = $\frac{120\,f}{Ns} = \frac{120\ X\ 50}{375}$ = **16**

Q.2. A 6-pole, 3-phase synchronous generator has 170 turns per phase on the armature. The output frequency is 50 Hz. If the alternator is star-connected to give an output voltage of 440 volt, determine: (a) the speed of alternator (b) flux per pole

Solution:

(a) Frequency, f = 50 Hz

No. of poles of the machine, P = 6

Speed, $N_s = \frac{120.f}{P} = \frac{120\ X\ 50}{6}$ = **1000 RPM**

$$E_{ph} = 4\varphi f T_{ph} \text{ x } 1.11 = 4.44\ \varphi\ f\ T_{ph} \text{ volts}$$

(b) Emf per phase,

Turns per phase T_{ph} = 170

In star connection phase voltage $E_{ph} = \frac{Line\ Voltage}{\sqrt{3}} = \frac{E_L}{\sqrt{3}} = \frac{440}{\sqrt{3}}$ = 254.04 V

Therefore Flux per $\phi = \frac{E_{ph}}{4.44\ f\,T_{ph}} = \frac{254.04}{4.44 \times 50 \times 170}$ **= 6.72 m Wb.**

ASSIGNMENT QUESTIONS

Q.1. Explain principle of operation of 3-phasesynchronous generator.

Q.2. Describe the applications of synchronous machine.

Q.3. Describe the constructional features of synchronous generator.

Q.4. Derive the emf equation of synchronous generator.

Q.5. Calculate the no-load terminal voltage of a 3-phase, 4 pole, star connected alternator running at 1500 rpm having following data :

Flux per pole = 66 mWb,

Total no. of armature slot = 10,

Distribution factor, k_d = 0.96.

Assume full pitch winding.

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